Thermal Control	Console Position: SPARTAN
Thermodynamics, Chemical Bonding and Stoichiometry	

External Thermal Control System (ETCS)

How is Heat Removed from the International Space Station?

Instructional Objectives

Students will

- determine change in temperature;
- determine the transfer of heat in a system;
- determine characteristics of a substance based on a structure; and
- determine a volume relationship.

Degree of Difficulty

This problem requires students to integrate several aspects of the AP Chemistry curriculum to obtain the solution. For the average AP Chemistry student, the problem may be moderately difficult.

Total Time Required

Teacher Prep Time: 10–15 minutes

Class Time: 75–100 minutes

(To decrease amount of class time, students may complete research as homework via the Internet using the ISSLive! website or mobile application.)

- Introduction: 20–30 minutes
- Student Research: 20–25 minutes
- Student Work Time: 25–30 minutes
- Post Conclusion: 10–15 minutes

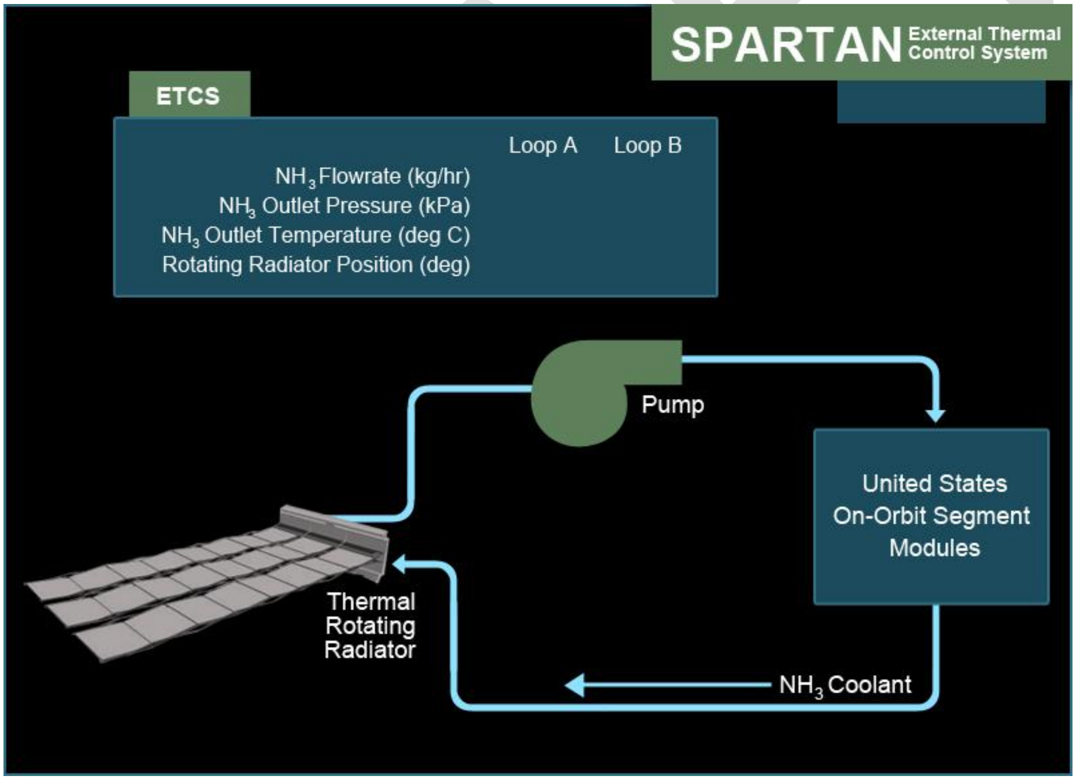
Lesson Development

This problem is part of a series of problems associated with the NASA International Space Station *Live!* (ISS*Live!*) website at http://spacestationlive.jsc.nasa.gov.

Teacher Preparation

- Review the Thermal Control System information on the ISS*Live!* website. This may be found at the *Operations* tab, under *Core Systems*.
- Review the Station Power, Articulation and Thermal Control (SPARTAN) Handbook, paying specific attention to the External Thermal Control System (ETCS). This handbook may be found at the SPARTAN console position in the 3D Mission Control Center environment (under the *Interact* tab, then *Explore Mission Control)*.
- Review the SPARTAN console display in the 3D Mission Control Center environment and the live data associated with the ETCS. The displays may be accessed by clicking on the console screens.

- Review the interactive activity at the SPARTAN console position in the 3D Mission Control Center environment *by clicking on the radiator* on top of the console. This activity demonstrates the operations of the ETCS.
- Prepare copies of the STUDENT WORKSHEET (Appendix B).



SPARTAN Console Display

Inquiry-Based Lesson (Suggested Approach)

1. Pose this question to the class:

   > *Since the International Space Station is exposed to extreme temperature fluctuations in space, how is a livable temperature range maintained for the onboard crew?*

2. Allow students to discuss the question in small groups or as a class. Have students build their own questions and possible solutions to the problem.
3. Distribute the STUDENT WORKSHEET to the class. Students may work individually or in small groups (2–3 members per group) to conduct the research. This may be assigned as homework.
4. In order to conduct the research, students should access the ISS*Live!* website and explore the 3D Mission Control Center. If needed, guide students to the SPARTAN console position. They should access the SPARTAN Handbook and SPARTAN console displays, as well as the interactive activity, as they prepare to answer the questions on the STUDENT WORKSHEET.
5. Once the research is completed, students may work individually to complete the questions on the STUDENT WORKSHEET. They should refer to the live data on the SPARTAN console displays located on the ISS*Live!* website to answer the entire problem.

Post Conclusion

6. A SOLUTION KEY (Appendix A) is provided below using data that is typical for normal operations of the ETCS. Students' answers will vary depending on the actual live data.
7. Have students discuss their answers in small groups or with the entire class and tie back to the original question:

   > *Since the International Space Station is exposed to extreme temperature fluctuations in space, how is a livable temperature range maintained for the onboard crew?*

8. Ask students to explain the ETCS and the data they used in their calculations.
9. Assessment of student work may be conducted by using the provided rubric (modeled after AP Free Response Question scoring).

Extension

Other possible uses for the ISS*Live!* website, focusing on SPARTAN and the Thermal Control System:

- Have students determine the molecular geometry and discuss whether ammonia is polar or non-polar.
- Have students view console data and, using a phase diagram, determine 1) what phase the ammonia is in and 2) at what pressure and temperature is the triple point.

AP Course Topics

Structure of Matter

- Chemical Bonding
  - Bonding forces
    - Types: ionic, covalent, metallic, hydrogen bonding and van der Waals (including London dispersion forces)
    - Relationships to states, structure and properties of matter

Reactions

- Thermodynamics
  - First Law: change in enthalpy
- Stoichiometry
  - Mass and volume relations with emphasis on the mole concept

NSES Science Standards

Science as Inquiry

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

Science in Personal and Social Perspectives

- Science and technology in local, national and global challenges

Physical Science

- Conservation of energy and increase in disorder

Science and Technology

- Abilities of technological design
- Understanding about science and technology

History and Nature of Science

- Science as a human endeavor
- Nature of scientific knowledge

Contributors

This problem is part of a series of problems developed by the ISS*Live!* Team with the help of NASA subject matter experts.

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Scoring Guide

Suggested 11 points total to be given.

Question		Distribution of points
1	*3 points*	1 point for the correct temperature change (1.a.) 1 point for the correct set-up (1.b.) 1 point for the correct numerical result for change in heat (1.b.)
2	*3 points*	1 point for the correct temperature change 1 point for the correct set-up 1 point for the correct numerical result for change in heat
3	*1 point*	1 point for the correct Lewis dot structure for ammonia
4	*1 point*	1 point for the correct explanation
5	*1 point*	1 point for the correct explanation
6	*1 point*	1 point for the correct numerical result for volume per day
7	*1 point*	1 point for the correct explanation

APPENDIX A

SOLUTION KEY

EXTERNAL THERMAL CONTROL SYSTEM (ETCS)

How is Heat Removed from the International Space Station?

The External Thermal Control System (ETCS) is primarily monitored and controlled by the Station Power, Articulation and Thermal Control (SPARTAN) flight controller. The SPARTAN flight controller works in the Mission Control Center for the International Space Station (ISS), along with a team of other flight controllers. These flight controllers monitor the operations of the external thermal and electrical systems of the ISS to maintain the temperature and supply power. To learn more, explore the 3D ISS Mission Control Center by accessing Explore Mission Control under the *Interact* tab on the ISS*Live!* website at http://spacestationlive.jsc.nasa.gov.

As the console position illustrates, the temperature reading of ammonia in the *ISSLive!* data is taken after the ammonia passes through the pump, and before it absorbs heat from the Internal Thermal Control System (ITCS). Once the ETCS takes on the heat from the ITCS, the ammonia averages a temperature of 7.5°C. At this point, the ammonia splits between two paths. On one path, the warmed ammonia proceeds to the radiators, where the heat is transferred and released to space. Once the heat is transferred, the average temperature of the ammonia is approximately -25°C. On the second path, the warm ammonia heads back toward the pump, where it eventually recombines with cool ammonia from the radiators. All of the ammonia is then transferred back through the pump and the loop continues.

1. According to the SPARTAN console display on the ISS*Live!* website:

    a. What is the current temperature of ammonia after *passin*g through the pump in Loop A? Determine the change in temperature once the ammonia has taken on heat from the ITCS.

    Based on the SPARTAN console display, assume temperature of: 3.9°C

    $\Delta T = 7.5 - 3.9 = 3.6°C$

    b. Assume that the heat loss between the ITCS and ETCS is negligible and that the specific heat capacity of ammonia is 4.6 $Jg^{-1}°C^{-1}$. Calculate the transfer of heat of the ammonia from the ITCS to the ETCS. (For mass of ammonia, visit the ETCS console display.)

    Based on the SPARTAN console display, assume mass of: 4,400.1 kg hr^{-1}

    $$4{,}400.1\ \text{kg}\,NH_3 \cdot \frac{1000\ \text{g}}{1\text{kg}} = 4{,}400{,}100.0\ \text{g}\,NH_3$$

    $q = m \cdot c \cdot \Delta T$

    $q = 4{,}400{,}100.0\ \text{g} \cdot 4.6\ \text{J g}^{-1}\ °\text{C}^{-1} \cdot 3.6\ °\text{C}$

q = 72,865,656 J or 72,865.66 kJ

2. Using the information above, calculate the transfer of heat between the ETCS to the radiators.

Assume mass of: 4,400.1 kg hr^{-1}

$$4{,}400.1\ \text{kg}\,NH_3 \cdot \frac{1000\ \text{g}}{1\text{kg}} = 4{,}400{,}100.0\ \text{g}\,NH_3$$

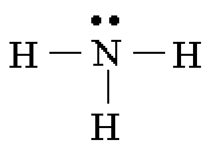
ΔT = -25 – 7.5 = -32.5°C

$q = m \cdot c \cdot \Delta T$

q = 4,400,100.0 g · 4.6 J g^{-1} $°C^{-1}$ · (-32.5 °C)

q = -660,000,000 J or -660,000 kJ

3. Draw the Lewis dot structure of the ammonia (NH_3) molecule.



4. Using the principals of intermolecular attractive forces, explain why ammonia has a lower freezing point than water.

Oxygen has a greater electronegativity than nitrogen. Therefore, the hydrogen bonding between oxygen and hydrogen in water molecules is stronger and harder to break than the hydrogen bonding that exists between nitrogen and hydrogen. Since the bonds in water molecules are stronger and take additional energy to break, a higher freezing temperature would indicate more energy is necessary to break those bonds.

5. What would be the benefit of using ammonia rather than water in the ETCS?

Since temperatures in space can drop very low, water could freeze within the lines. Ammonia has a lower freezing point than water.

6. According to *ISSLive!*, what is the flow rate of Loop B? What is the volume in liters per day being pumped in Loop B at the current rate? (The density of liquid ammonia is 0.6 g/cm^3.)

For sample solution use 1500 kg/hr:

$$\frac{1500\ \text{kg}}{\text{hr}} \cdot \frac{1000\ \text{g}}{\text{kg}} \cdot \frac{24\ \text{hr}}{1\text{day}} \cdot \frac{1\text{cm}^3}{0.6\ \text{g}} \cdot \frac{1\text{L}}{1000\ \text{cm}^3} = 60{,}000\ \frac{\text{L}}{\text{day}}$$

7. The SPARTAN console monitors the ETCS very carefully for leaks. Explain why this is essential on the ISS.

Ammonia is a gas when it is at room temperature. An ammonia gas leak inside the ISS cabin would be harmful to crewmembers.

APPENDIX B

STUDENT WORKSHEET

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1. According to the SPARTAN console display on the ISS*Live!* website:

    a. What is the current temperature of ammonia after *passin*g through the pump in Loop A? Determine the change in temperature once the ammonia has taken on heat from the ITCS.

    b. Assume that the heat loss between the ITCS and ETCS is negligible and that the specific heat capacity of ammonia is 4.6 $Jg^{-1}{}^{\circ}C^{-1}$. Calculate the transfer of heat of the ammonia from the ITCS to the ETCS. (For mass of ammonia, visit the ETCS console display.)

2. Using the information above, calculate the transfer of heat between the ETCS to the radiators.

3. Draw the Lewis dot structure of the ammonia (NH_3) molecule.

4. Using the principals of intermolecular attractive forces, explain why ammonia has a lower freezing point than water.

5. What would be the benefit of using ammonia rather than water in the ETCS?

6. According to *ISSLive!*, what is the flow rate of Loop B? What is the volume in liters per day being pumped in Loop B at the current rate? (The density of liquid ammonia is 0.6 g/cm^3.)

7. The SPARTAN console monitors the ETCS very carefully for leaks. Explain why this is essential on the ISS.